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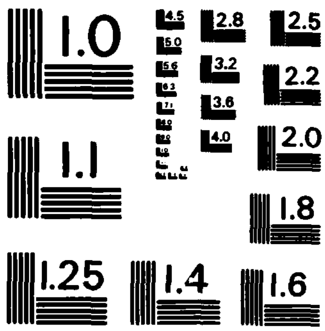

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ASSESSMENT OF VISUOSPATIAL ABILITIES USING COMPLEX COGNITIVE TASKS

By

Gary L. Allen, Principal Investigator

Final Report
For the period June 1, 1983 to April 1, 1984

Prepared for the
Air Force Office of Scientific Research
Building 410, Room A-111
Bolling Air Force Base
Washington, D.C. 20332

Under
Research Grant AFOSR-83-0161
Major Richard W. Kopka, Scientific Officer

November 1984

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Two studies were conducted in separate areas concerned with visuospatial abilities. The first study was designed to examine the effects of type of instruction (verbal versus graphic) and sex of subject on the acquisition of procedural knowledge in a spatial task. The spatial task employed was a computerized maze learning task, with trials to criterion and errors to criterion serving as dependent variables. Results indicated that graphic instructions led to fewer errors and trials to criterion than did verbal

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instructions. However, the performance of males was not superior to that of females, and the hypothesized interaction involving type of instruction and sex of subject was not found. Correlations between psychometric measures of cognitive abilities and measures of maze learning were easily interpreted for learning under graphic instructions but were difficult to interpret for learning under verbal instructions. These findings suggested the need for additional research focusing on (a) replicating the current results, (b) delineating the factors underlying individuals' learning effectiveness under different types of instructions, and (c) examining individuals' awareness of the relationship between learning effectiveness and type of instruction in visuospatial tasks.

The second study was designed to determine the relationship between performance on traditional paper-and-pencil tests of spatial ~~abilities and performance on a task required macrospatial cognitive skills.~~ A test battery was selected to include tests involving visualization, spatial orientation, spatial reasoning, visual memory, and perceptual speed abilities; administered with this battery was the Scrambled Route Task, which required the acquisition of accurate spatial knowledge from a scrambled series of slides depicting a real-world route. A factor analysis performed on test results yielded a three-factor solution. The first factor was interpreted as higher-order spatial reasoning abilities, the second factor as temporospatial integration skills as demanded by the macrospatial task, and the third factor as lower-order spatial recall and recognition memory abilities. These results suggested the need for additional studies to (a) develop and standardized new macrospatial tasks appropriate for testing settings and (b) establish the reliability and external validity of such tasks.

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1. Introduction

1.1 Overview

Recent technical and conceptual advances in cognitive psychology have stimulated efforts to develop a new technology for the assessment of cognitive abilities. The combination of computerized testing and an information processing view of human cognitive activities, for example, has opened a new realm of assessment possibilities that is being explored with basic research.

The two studies described in this project report are representative of efforts on the part of cognitive psychologists to adapt tasks developed in basic laboratory research for the study of individual differences in cognitive abilities. Each of the two studies is concerned with a different research problem, but both fall under the rubric of studies in spatial cognition. As a specific subdomain of cognitive psychology, the study of spatial cognition is significant for both practical and theoretical reasons.

From a practical point of view, tests of visuospatial abilities have been shown to have predictive validity with regard to mechanical and artistic aptitude, and visuospatial components have been identified in many occupations (see Ghiselli, 1966; McGee, 1979; Smith, 1964). In addition, there is the relatively unexplored possibility that visuospatial abilities could be exploited more strategically in the service of training and education, enterprises that tend to rely heavily upon verbal/linguistic abilities.

From a theoretical point of view, spatial cognition has unique properties as an information processing phenomenon. Traditionally, global models of human cognition have been based on evidence obtained from studies involving verbally-oriented learning, memory, and problem-solving tasks; most theories of intelligence emphasize verbal comprehension and reasoning abilities. However, there is increasing experimental, physiological, and psychometric evidence of an autonomous visuospatial information processing system at work in human cognition. Consequently, global models of intellectual functioning will eventually be modified to accommodate new findings regarding these autonomous processes.

1.2 Objectives

The first study in this project was concerned with the relationship between cognitive abilities and visuospatial learning. Very little is known about factors affecting the acquisition of procedural knowledge in a spatial task, and even less is known about individual differences in these factors. The purpose of this study was to (a) compare learning effectiveness in a visuospatial learning task (i.e., learning the path through a computer-presented maze) under two sets of instructions, one based on verbal representation of the path and one based on a graphic representation of the path, and (b) determine what cognitive abilities may be related to learning under each of these instructional conditions.

The second study in this project was concerned with spatial abilities and macrospatial cognitive processes. Although spatial thought and spatial behavior in large-scale environments are an important part of everyday life, there is little evidence to indicate that the abilities necessary for these

activities are assessed by traditional paper-and-pencil tests of spatial abilities. New tasks may be needed to measure macrospatial cognitive skills. The purpose of this study was to determine the relationship between spatial abilities as assessed by a battery of traditional cognitive tests and macrospatial skills as assessed using a task requiring the acquisition of route knowledge from a pictorialized route. The route learning task, called the Scrambled Route Task, required the ability to mentally reorganize, or temporospatially integrate, a route because the scenes comprising the route were presented in a scrambled rather than logically sequenced order.

Both studies were designed to be an initial study in a series dealing with the same basic issues. The long-range goal in each case is the development of new assessment instruments that could be of use in differentiating among individuals with regard to their visuospatial information processing capabilities.

2. Experiment 1

Cognitive Abilities and the Acquisition of Spatial Knowledge

Comprehending and remembering route directions are common cognitive exercises in everyday life and, thus, they provide an excellent focus for laboratory research concerned with the acquisition of procedural knowledge through instruction. Essentially, route knowledge is information concerning how to reach a given destination from a particular starting point by coordinating a sequence of locomotor activities with a sequence of environmental features (Allen, 1982; Moar & Carleton, 1982; Siegel & White, 1975). As is the case with most procedural knowledge, route knowledge can be readily portrayed in terms of a production system, consisting of Conditions, i.e., environmental features, and Actions, i.e., locomotor patterns (Kuipers, 1978).

Attempts to convey procedural knowledge to a novice necessarily incorporate the information contained in the sequence of Condition-Action pairings. Consequently, instructions typically consist of a list of temporally ordered steps, sometimes accompanied by a pictorial representation of objects or events. Route directions also frequently take the form of a series of ordered steps specifying a spatial progression; however, verbal route directions are frequently either accompanied by or superceded by a cartographic representation of the route.

No doubt, route directions containing both verbal and graphic informa-

tion are more useful than those consisting of either type of information alone. However, the question of which mode of instruction is by itself more useful does arise. Accompanying this question is the more interesting issue of individual differences in the effectiveness of the two instruction modes. It is possible that individuals whose verbal skills are superior to their spatial skills benefit more from verbal route directions than from graphic route directions, while individuals whose spatial skills are superior to their verbal skills benefit more from graphic instructions rather than a list of verbal commands.

The consistent findings that males tend to score higher than do females on psychometric tests of spatial abilities and that females tend to score higher than do males on psychometric tests of verbal abilities (see Maccoby & Jacklin, 1974; McGee, 1979; Harris, 1981) provide one approach to examining this issue of individual differences. To the extent that verbal and spatial abilities measured by psychometric instruments are involved in the acquisition of procedural knowledge in a spatial task, females would be expected to learn more rapidly under verbal instructions than under spatial instructions, while males would be expected to learn more rapidly under spatial instructions.

These expectations were tested as hypotheses in an experimental study in which subjects were tested using a computerized maze learning task. Specifically, it was hypothesized that (a) females would require fewer trials to criterion and make fewer errors when provided verbal instructions to the maze than when provided graphic instructions and (b) males would require fewer trials to criterion and make fewer errors when provided graphic instructions to the maze than when provided verbal instructions. On

the basis of previous research showing a male superiority in maze learning (McGee, 1979), it was also hypothesized that males would learn the maze in fewer trials and with fewer errors than would females with the two instructional conditions combined.

In addition to the maze learning procedure, subjects also were administered a small battery of psychometric tests designed to assess specific cognitive skills that might be involved in maze learning. Specifically, the tests were constructed to assess memory span, associative memory, visual memory, and flexibility of closure, i.e., the ability to disembed a pattern from its perceptual context. It was hypothesized that memory span and associative memory would be positively correlated with rapid and accurate learning of the maze under verbal instructions, which consisted of a list of Direction-Distance pairs. In contrast, visual memory and flexibility of closure were predicted to result in positive correlations with measures of rapid and accurate maze learning under graphic instructions. Additionally, the scores provided some insight into the validity of the assumption that males and females differed on abilities relevant to maze learning.

2.1 Method

2.1.1 Subjects. Data were collected from 24 male and 24 female Air Force basic trainees at Lackland Air Force Base, Texas. These groups were assigned at random to this study from a large pool of trainees during regularly scheduled testing sessions.

2.1.2 Materials. The mazes used in the spatial learning task consisted of six-by-six block matrices presented by means of microcomputer. A cursor was moved along the correct route through the maze by entering the correct command in the form of a direction ("U" for up, "D" for down, "L" for left, and "R" for right) and a distance (from "1" to "6" blocks). Direction and distance information was entered sequentially in response to the prompts "What direction?" and "How many blocks?". Incorrect entries resulted in an error message and a request to enter new information; correct entries resulted in movement of the cursor with a trail marked by a broken line. Two mazes were used in the study, each of which involved 21 direction-distance pairs for solution.

Graphic instructions for the maze consisted of the six-by-six block matrix with a broken line indicating the correct path through the maze. Specifically, the cursor moved through the maze once, marking the path with the broken line. Graphic instructions remained visible for a two-minute study period. Verbal instructions consisted of 21 direction-distance pairs presented as single letters and single digits (e.g., "U-2" indicated "Go up two blocks"). These instructions were presented in three columns of seven pairs.

In addition, a three-by-three block matrix was devised as a practice maze to demonstrate the two types of instructions and the procedure for entering movement commands. The solution to this practice maze involved three direction-distance pairs.

The pencil-and-paper battery of cognitive tests used in the study consisted of the Visual Digit Span Test (designed to assess memory span), the Object-Number Test and First & Last Name Test (designed to assess associ-

ative memory), the Copying Test (designed to assess flexibility of closure) and the Shape Memory Test and Building Memory Test (designed to assess visual memory). All psychometric tests were from Ekstrom, French, and Harman (1976). The battery is shown in Table 1.

Table 1. Battery of Cognitive Ability Tests

Test	Source	Major Factor
Visual Digit Span	Kit of Factor Referenced Cognitive Tests	Memory Span
Object Number	" "	Associative Memory
First & Last Names	" "	" "
Copying	" "	Flexibility of Closure
Shape Memory	" "	Visual Memory
Building Memory	" "	" "

2.1.3 Equipment. The maze learning task was administered on Terak 8510A microcomputers, which feature standard microprocessors, 64 K RAM, and two eight-inch floppy disk drives. Instructions and mazes were presented on 12-inch monochrome Terak CRTs, which afford 320 x 240 resolution. The operating system used for the study was UCSD-Pascal Version 2.0.

2.1.4 Procedure. Subjects participated in a pencil-and-paper testing session and a computerized testing session. During the pencil-and-paper testing session, an experimenter provided instructions for each of the six cognitive tests. Prior to the computerized testing session, the experimenter explained the purpose of the maze learning task and provided

information regarding the keys on the computer keyboard that would be used in the task. All specific instructions were provided by the computer.

During the computerized testing session, subjects read a description of the task, worked to solution on a three-step practice maze, worked to solution on a 21-step maze using graphic instructions, and worked to solution on a 21-step maze using verbal instructions. Solution to the 21-step mazes involved achieving a criterion of two successive errorless trips through the maze. A break of approximately 10 minutes was provided after criterion was achieved on the initial 21-step maze.

Male and female subjects were tested in groups of 24. Half of the subjects within each sex learned under graphic instructions for their first maze and verbal instructions for their second; the other half learned under verbal instructions first and graphic instructions second. The order of the two different mazes was counterbalanced within these sub-groups.

2.2 Results

Data from the study were analyzed to (a) determine the effect of instruction condition and sex of subject on the number of trials to criterion and the number of errors to criterion in maze learning, and (b) explore the relationships among measures of maze performance under different instructional conditions and measures of cognitive abilities as assessed on pencil-and-paper tests.

2.2.1 Effects of Instructions and Sex of Subject. On the basis of preliminary analyses revealing no significant differences between or interactions involving the two different mazes, the number of trials to

criterion and the number of errors to criterion were analyzed in separate 2 (sex of subject) x 2 (order of presentation for instructional conditions) x 2 (instructional condition) mixed ANOVAs with 12 subjects per cell. The analysis of trials to criterion yielded a significant main effect for instructional condition, $\underline{F}$ (1, 44) = 15.31, $\underline{MSe}$ = 4.57. (The $\underline{p}$ < .05 level of statistical significance was applied in all analyses in this study.) Criterion was achieved after an average of 4.8 trials with graphic instructions as compared to a mean of 6.5 trials with verbal instructions. No other main effects or interactions achieved statistical significance in this analysis.

The ANOVA performed on errors to criterion yielded significant effects of order of presentation, $\underline{F}$ (1, 44) = 4.99, $\underline{MSe}$ = 549.8, and instructional condition, F (1, 44) = 27.40, $\underline{MSe}$ = 272.7, and a significant interaction involving these two factors, F (1, 44) = 4.55, $\underline{MSe}$ = 272.7. No other main effects or interactions were significant. The significant main effects indicated that subjects who had spatial instructions first made fewer errors to criterion (mean = 18.3) than did subjects who had verbal instructions first (29.0) and that spatial instructions led to fewer errors than did verbal instructions (14.8 versus 32.4).

The significant interaction involving order of presentation and instructional condition signified that the relative advantage of learning with graphic instructions was exaggerated following a learning experience with verbal instructions, primarily because of the increased number of errors when verbal intructions were provided initially. The mean number of errors to criterion with verbal instructions was 41.4 when verbal instructions accompanied the first maze to be learned and 23.5 when verbal instructions

accompanied the second maze to be learned. The comparable means with graphic instructions were 16.5 and 13.0, respectively.

2.2.2 Sex Differences in Test Performance. The absence of significant main effects and interactions involving the sex of subject factor in these ANOVAs raised questions concerning the often made assumptions that the mean level of spatial abilities in a female subject sample will be below that of a male sample and that the mean level of verbal abilities in a female sample will be above that of a male sample. The battery of cognitive tests administered in the present study provided a means of checking the validity of this assumption in this instance.

A series of independent $\underline{t}$ tests were conducted to determine sex differences in performance on the six cognitive tests. Females produced a higher mean score on the Object-Number test, $\underline{t}$ (46) = 2.30, and the First and Last Name test, $\underline{t}$ (46) = 3.30, both of which involved the same type of associative memory task that was required by maze learning under verbal instructions. However, there were no significant sex differences on the remaining four tests, all $\underline{t}$'s < 1.69. Thus, the male and female samples did not differ significantly in their visual memory capacities, flexibility of closure, and memory span, but the females showed superiority in associative memory.

2.2.3 Relationship Between Maze Learning and Cognitive Abilities. The number of trials to criterion and the number of errors to criterion were included with the scores of the six psychometric tests in a Pearson Product-Moment Correlation analysis (see Table 2). As expected, intercorrelations of test scores revealed significant positive correlations between

tests assessing the same cognitive factor; the coefficient for the two measures of associative memory, The Object-Number Test and the First and Last Name Test, was .72, and that for the two measures of visual memory, Shapes of Objects and Building Memory, was .47. In addition, performance on the Shapes of Objects test (designed to assess visual memory) was significantly correlated with performance on the Object-Number test (.36) and the First and Last Name test (.47) (both designed to assess associative memory) and on the Digit Span test (.26). No other correlations among psychometric tests were significant.

Table 2. Pearson Correlation Coefficients for cognitive Ability Tests and Maze Learning Test

Span	----									
Obj-No	+.03	----								
Names	+.04	+.72	----							
Copy	-.15	+.06	-.03	----						
Shape	+.26	+.36	+.47	+.06	----					
Bldg	+.17	+.22	+.19	+.22	+.47	----				
Trials-Graphic	-.21	+.21	+.20	-.25	-.09	-.33	----			
Errors-Graphic	-.13	+.16	+.16	-.28	-.06	-.33	+.90	----		
Trials-Verbal	+.01	+.25	+.12	-.11	-.14	-.32	+.44	+.43	----	
Errors-Verbal	+.24	+.03	+.01	-.09	-.05	-.27	+.27	+.37	+.68	----
	Span	Obj-No	Names	Copy	Shape	Bldg	Trials	Errors	Trials	Errors

All intercorrelations among maze learning measures were significant. As expected, errors to criterion and trials to criterion produced high correlations under graphic (.90) and verbal (.68) conditions. Trials to

criterion were correlated under both conditions (.44), as were errors to criterion (.37). The coefficient involving trials to criteria under graphic instructions and errors to criteria under verbal instructions was .27, and that involving trials under verbal instructions and errors under graphic instructions was .43.

Scores on two psychometric tests were correlated with rapid and accurate learning of the maze under graphic instructions. Coefficients involving the Copying test (a test of flexibility of closure) on the one hand and trials to criteria and errors to criteria on the other hand were -.25 and -.28, respectively. (A negative correlation indicates that higher test scores were related to fewer trials and errors to criteria.) Scores on the Building Memory test, one of the two instruments used to assess visual memory, were correlated -.33 with trials and -.33 with errors to criterion.

The correlational analyses also revealed four significant correlations between psychometric test scores and maze learning measures under verbal instructions. As in the case of graphic instructions, performance on the Building Memory test was significantly related to trials to criterion (-.32) and errors to criterion (-.27) under verbal instructions. However, the remaining two significant correlations marked a radical departure from aforementioned results. Performance on the Object-Number test was positively correlated with trials to criterion under verbal instructions (.25), and performance on the Digit Span test was positively correlated with errors to criterion under verbal instructions (.24). In sum, superior performance on this associative memory test and on this test of memory span were related to poorer performance on the maze learning task in the verbal instruction condition.

2.3 Discussion

The evidence indicates clearly that, as expected, learning the maze from graphic instructions was easier than learning it from verbal instructions. However, the prediction that males would learn the maze more rapidly and with fewer errors than would females was not substantiated, and the anticipated interaction in which males were expected to perform better with spatial instructions and females were expected to perform better with verbal instructions was not found.

The absence of sex differences in visual memory, as measured by psychometric tests, may account, in part, for the failure to support these hypotheses in the present study. The interaction involving instruction type and sex of subject was predicted on the basis of the assumption that males' visual memory capabilities would be, on average, superior to those of females and that females' associative memory capabilities would be on average superior to those of males. Only the latter of these assumptions was supported on the basis of psychometric test results. Importantly, these findings call attention to the often overlooked proposition that sex-related differences in performance on spatial tasks are the result of differences in cognitive skills, not differences in gender per se.

The correlations among psychometric test scores and performance measures from the maze learning task under graphic instructions are subject to straightforward interpretation. Flexibility of closure (as measured by the copying test) and visual memory (as measured by the Building Memory test) were related to quick and accurate learning under graphic instructions. Flexibility of closure refers to the ability to disembed a pattern from its

perceptual concept; presumable in this case, the line representing the path through the maze was abstracted from the other lines defining the block maze. Visual memory is obviously involved in storing and retrieving path information once it is disembedded.

Unfortunately, the correlations involving maze learning under verbal instructions are anything but straightforward. As was the case with graphic instructions, visual memory (as measured by the Building Memory test) was associated with rapid and accurate learning. However, greater memory span (as measured by the Digit Span test) was related to decreased accuracy during learning, and greater associative memory (as measured by the Object-Number test) was related to slower acquisition in terms of trials to criterion. These results were opposite of reasonable expectations. If any test should predict maze learning under verbal instructions, which required memorization of paired-associates (i.e., direction commands paired with digital distances) it would be the Object-Number test, which requires the memorization of paired associates (i.e., object names paired with numbers).

One explanation for this pattern of results is based on the fact that learning from verbal instructions was inefficient compared to learning from grpahic information. It may have been the case that individuals with lesser memory skills abandoned their attempts to learn from the verbal instructions during study phases of the procedure in favor of learning from the visuospatial feedback provided during test phases. In contrast, individuals with superior memory spans and associative memory ability may have persevered in learning the maze from verbal commands, a more difficult and time-consuming method of acquiring spatial knowledge.

A closely related explanation for this correlational finding is based

on the proposition that the task of memorizing a list of spatial commands is substantially different from that of constructing a spatial representation of that information. Botn tasks were involved in maze learning under verbal instructions, but it is possible that memorization activity interfered witn the construction of a spatial representation of the path through the maze, perhaps by demanding too great a portion of processing capacity.

It is interesting to note that performance on one test of visual memory (Building Memory test) and not another (Shape Memory test) was correlated with fast and accurate maze learning under both instructional conditions. The most likely reason for this finding involves verbal mediation. The Building Memory test involves memory for spatial layouts of buildings and thus affords many opportunities for labeling visual features to be remembered. In contrast, the Shape Memory test involves memory for irregular shapes. The computerized maze learning task required visuospatial memory, but the path through the maze was communicated to the computer in terms of verbal commands. Clearly, verbal mediation could play a critical role in this task. Thus, the Building Memory test was more closely related to the maze learning task than was the Shape Memory test, despite the fact that performance on the two tests of visual memory were highly positively correlated.

In summary, the results from the present study indicated that (a) spatial learning was faster and more accurate with graphic instructions along than with verbal instructions alone, and (b) spatial learning under graphic instructions involves the abilities to abstract important visual information from its context and to store and retrieve this abstracted information. The findings also suggested that (a) sex of subject should be regarded as an

intervening variable in studies of spatial cognition, and (b) the ability to store and retrieve verbal information per se does not facilitate and, in fact, may retard efforts to coordinate verbally presented spatial information with a graphic representation of that information. The results suggest the validity of the maze learning task with graphic instructions as a computerized assessment instrument for measuring visuospatial memory. They also point to the need for additional research on individual differences in the acquisition of procedural knowledge in spatial tasks.

3. Experiment 2:

Spatial Abilities and Macrospatial Cognition

The empirical relationship between performance on tests of spatial abilities and performance on experimental macrospatial cognitive tasks has not yet been firmly established. There appear to be two different facets to this problem. The first of these concerns the interrelationships among psychometric tests; the second concerns the lack of standardization for macrospatial tasks.

The number and description of spatial abilities has been a matter of debate for decades (see Cattell, 1971; Guilford, 1967; Thurstone, 1938). Typical of the lack of consensus on this issue is the comparison of McGee's (1979) conclusions that there exist two spatial factors (visualization and spatial orientation) to Lohman's (1979) independent determination that there are three factors (visualization, spatial relations, and spatial orientation), one of which (orientation) cannot be measured well with existing instruments.

The lack of a standardized experimental methodology for assessing knowledge of large-scale spatial environments is not surprising for several reasons. Spatial cognition as a research area is relatively new, and the relative merits of various methodologies are being debated in the research literature. For example, the use of a map-drawing method is considered problematic because it confounds cartographic skills with environmental

knowledge per se. Also, spatial cognition is a multifaceted problem that involves a range of phenomena ranging from recognition of environmental features to an internal representation of a geographic region.

The purpose of the present study was to explore relationships between spatial abilities as measured using psychometric tests and macrospatial cognitive processes as assessed using an experimental task. Psychometric tests were selected from the Air Force Human Resources Laboratory's test library to assess (a) spatial visualization, defined as the ability to manipulate the image of spatial patterns into other arrangements; (b) spatial orientation, defined as the ability to perceive spatial patterns or to maintain orientation with respect to objects in space; (c) perceptual speed, defined as speed in comparing visual information; and (d) visual memory, defined as the ability to remember the configuration of figural material. The preceding definitions were obtained from Ekstrom et al. (1976).

The macrospatial task selected for inclusion in the study was the Scrambled Route Task, which requires subjects to make accurate distance estimates along a route that learn through observing a scrambled series of slides depicting the course of that route (Allen, Siegel and Rosinski, 1978). This task was selected for four reasons. First, no verbal mediation or map drawing skill was required for task performance. Second, the task involved route learning, which is a fundamental and very important example of a real-world macrospatial task. Third, the task requires a temporo-spatial integration process, i.e., the selection and organization of environmental features, assumed to be critical in all macrospatial tasks. Fourth, because experience in the environment is approximated using a sequence of slides, the task can be presented in a laboratory setting.

On the basis of previous research, it was predicted that performance on the psychometric tests of spatial ability would not be strongly related to performance on the macrospatial task (Pearson, 1981). However, this previous study did not involve as large a range of factor-referenced tests and included a slide-based Landmark Selection task rather than the Scrambled Route task. Additional evidence of the absence of a strong relationship between psychometric measures and macrospatial task measures would support the proposition that current tests of spatial abilities do not tap those processes involved in macrospatial cognition.

3.1 Method

3.1.1 Subjects. Data were collected from 237 basic trainees at the Air Force Human Resources Laboratory's Experimental Testing Facility at Lackland AFB, Texas. Males and females were tested in approximately a 2:1 ratio.

3.1.2 Materials. The battery of tests, which was selected from AFHRL's test library, included (a) Estimation of Length, which required the matching of bars of equal length; (b) Shapes of Objects, which required the visualization of facets on a bisected object; (c) Rotated Blocks, which required the anticipation of the appearance of a rotated object; (d) Viewing Position, which required the anticipation of the appearance of an object under conditions of viewer rotation; (e) Form Board, which required the visual construction of a pattern from its parts; (f) Pattern Completion, which required the completion of a figure based on rules induced from a previous figure; (g) Letter Matching, which required rapid identification of letter sequences; (h) Position Recall, which required memory for the loca-

tion of an object on a printed page; and (i) Object Memory, which was another test requiring memory for the location of an object on a printed page. The source of these tests and cognitive factors they involve are shown in Table 3. Subjects' performance on each test was scored by the standard convention: number of items correct minus the number of items incorrect over the number of response options minus one.

Table 3. Battery of Visuospatial Ability Tests

Test	Source	Major Factor
Estimation of Length	Technical School Spatial Battery	Undetermined
Shapes of Objects	" "	Visualization
Rotated Blocks	" "	Spatial Orientation
Viewing Position	" "	" "
Form Board	" "	Visualization
Pattern Completion	Nonverbal Aptitude Battery	Logical Reasoning
Letter Matching	" "	Perceptual Speed
Position Recall	Individual Test	Visual Memory
Object Memory	Individual Test	Visual Memory

The Scrambled Route consisted of 60 slides taken at 20 m intervals along a 1 km walk through an urban landscape; the walk involved 60 rather than 50 slides because "extra" slides were used to ensure perceptual continuity while turning corners. During the presentation phase of the task, the slides portraying the walk were presented in a random order using a Kodak Ektagraphic slide projector controlled by an automatic timing device that projected each slide for 5 sec. During the test phase of the task, a single

slide was designated as a standard reference point, and a succession of 28 slides were used as distance estimation targets. Subjects were instructed to estimate distances to the nearest part of the traversed path visible in each slide using a magnitude estimation procedure without a standard distance. Subjects' performance on the task was assessed by computing log estimated distance as a function of log actual distance in a linear regression analysis. The exponent from the resulting power function and the log estimate-to-log distance correlation coefficient reflected the relative accuracy of each subjects performance.

3.1.3 Procedure. Testing was done in a large classroom setting. Each subject received a booklet containing all tests and a series of standardized multiple choice answer sheets. As subjects worked through the succession of tests, instructions were read by a test administrator and any questions were answered by either the administrator or one of several test proctors. A 15 minute break was provided after five tests had been completed. The entire procedure required approximately 3 hours to complete.

3.2 Results

A Pearson Product-Moment correlational analysis performed on subjects' test scores revealed the pattern of relationships shown in Table 4. Inspection of these correlation coefficients indicate clearly a moderate to high degree of relatedness among traditional psychometric tests of spatial abilities but not much of a relationship between psychometric test scores and performance measures from the Scrambled Route Task. Generally speaking, correlations were highest for pairs of tests believed to tap the same cognitive factor. For example, the Shapes of Objects test and Form Board test,

Table 4. Pearson Correlation Coefficients Spatial Ability Tests and Scrambled Route Task

	Est Length	Shapes Obj	Rotated Bl	View Posit	Form Board	Pat Compl	Let Match	Posit Rec	Obj Memory	Scrambled Route	Scrambled Route
Est Length	----										
Shapes Obj	+.21	----									
Rotated Bl	+.35	+.51	----								
View Posit	+.29	+.53	+.49	----							
Form Board	+.31	+.64	+.55	+.52	----						
Pat Compl	+.30	+.41	+.54	+.52	+.51	----					
Let Match	+.38	+.12	+.21	+.26	+.20	+.29	----				
Posit Rec	+.25	+.17	+.27	+.31	+.19	+.30	+.34	----			
Obj Memory	+.31	+.20	+.29	+.34	+.22	+.32	+.26	+.43	----		
Scrambled Route exponent	+.01	+.14	+.18	+.14	+.14	+.19	-.01	+.14	-.02	----	
Scrambled Route exponent	+.05	+.17	+.23	+.18	+.20	+.27	-.07	+.17	+.05	+.85	----

both designed to assess visualization, correlated more highly with each other than either did with any other test. The same can be said of the Position Recall test and Object Memory tests, both of which were designed to assess visual memory. The Rotated Block test and Viewing Position test, both of which were believed to assess spatial orientation ability, were highly correlated, but they also were both closely related to tests of visualization. The two measures from the Scrambled Route Task, i.e., slopes and correlations, produced the highest correlation in this analysis, but as previously indicated, correlations between these measures and scores from the pencil-and-paper battery were modest, at best.

A principal component factor analysis with Varimax rotation was performed on the matrix obtained from the correlational analysis. A three-factor solution was obtained (See Table 5). The first factor produced an eigenvalue of 3.51 and accounted for 60.2% of the variance in the solution; the second factor produced an eigenvalue of 1.56 and accounted for 26.7% of the variance; and the third factor produced an eigenvalue of .76 and accounted for 13.1% of the variance.

A factor loading of .40 or above was used as a criterion to establish which tests loaded on each of the three factors. The first factor was interpreted as Spatial Reasoning because tests loading on this factor (i.e., Shapes of Objects, Form Board, Rotated Blocks, Viewing Position, and Pattern Completion) required the cognitive analysis and transformation of complex visuospatial stimuli. The second factor was interpreted as Macrospatial Temporospatial Integration because it required the acquisition of accurate route knowledge under conditions of temporospatial discontinuity. Only the measures from the scrambled Route Task loaded on this factor. The third

Table 5. Varimax Rotated Factor Matrix for Spatial Ability Tests and Scrambled Route Task

	Factor 1	Factor 2	Factor 3
Est. Length	0.26856	-0.02507	0.47319*
Letter Matcn	0.11820	-0.00446	0.53952*
Shapes of Obj	0.76504*	0.06182	0.07886
Form Brd	0.78822*	0.07072	0.16280
Rotated Bl	0.63638*	0.12784	0.31341
Viewing Pos	0.80960*	0.08150	0.36147
Pattern Compl	0.54949*	0.16413	0.39528
Position Rec	0.11390	0.13061	0.50540*
Obj Memory	0.18673	-0.02420	0.57165*
Scrambled Route Exponent	0.10252	0.92056*	-0.01158
Scrambled Route Correlation	0.14621	0.90763*	0.07754

*Denotes significant factor loadings.

factor, which was relatively weak, was interpreted as Visual Memory, because the tests loading on this factor (i.e., Position Recall, Object Memory, Estimation of Length, and Letter Matching) required relatively low-level encoding, comparison, and retrieval processes.

3.3 Discussion

The preceding results speak directly to two issues in spatial cognition. The first issue concerns the development of a taxonomy of spatial abilities as assessed by traditional paper-and-pencil cognitive tests. The results of this study provide little support for the generally-accepted discrimination between visualization and spatial orientation and even less support for the concept of three distinct spatial factors, i.e., visualization, spatial relations, and spatial orientation.

The failure to identify these as different factors in this study does not argue against their existence, but it does suggest that these are very closely related abilities and probably will be identified as separate factors only in studies involving specific marker tests and particular factor analytic techniques. What did appear in the present study was a seemingly sensible distinction between tests requiring lower-order recognition and recall abilities and tests requiring higher-order visuospatial abilities such as the cognitive manipulation of patterns and the inference of relationships. The identification of these as separate factors is compatible with a process-oriented approach to classifying basic cognitive processes (Carroll, 1976; Rose, 1980), in that the tests comprising the two factors are readily distinguished by the number and type of requisite processes.

The second issue highlighted by the results of this study concerns the

relationship between spatial abilities as measured by standard psychometric instruments and macrospatial cognition as required by the Scrambled Route Task. The fact that the two measures of performance on this task represented a separate factor from the two derived from the test battery indicates a weak relationship between traditional measures of spatial abilities and measures of performance on spatial tasks in large-scale environments. It is worthwhile to note that Pearson (1981) also found that macrospatial tasks based on a pictorialized route-learning procedure represented a factor distinct from those based on psychometric measures of spatial abilities.

Although there have been two studies supporting the contention that paper-and-pencil tests do not assess macrospatial abilities, it must be acknowledged that the issue is far from being settled. The macrospatial tasks employed, such as the Scrambled Route Task, are not standardized, and their reliability and validity have not been established. In other words, they remain experimental tasks rather than psychometric instruments. Establishing external validity may be the most important matter in this regard. Thus far, there is no empirical evidence that macrospatial tasks involving pictorialized routes are representative of or similar to the types of spatial task that are performed in everyday environments. Nevertheless, these tasks do represent progress toward the objective of developing laboratory procedures for examining macrospatial cognitive processes.

4. Implications and Conclusions

The results of the two studies in this project indicate new directions for research focusing on the assessment of cognitive abilities and the consequences of such assessment for the performance of visuospatial tasks. Additional studies along these lines could conceivably lead to conceptual innovations in the measurement of spatial abilities.

The findings of the initial study suggest that the Maze Learning Task under graphic instructions represents an excellent test of visuospatial learning abilities. This task presents a short-term learning situation of high understandability and medium difficulty. Such a task can easily be incorporated into a computerized battery of cognitive tests. In addition, the study of procedural learning in a spatial task also raises the familiar aptitude-treatment interaction issue (see Cronbach and Snow, 1977). Procedural knowledge with important visuospatial components can be conveyed in either verbal or graphic format, and it is reasonable to assume that a match between task demands and instructional format would yield the most effective learning. However, it is also the case that the relative magnitude of verbal and spatial abilities at an individual's disposal affects that individual's rate of information acquisition under different instructional formats.

The issue of individual differences in the ability to learn from different formats deserves further research attention. Future studies might focus on establishing a cognitive profile of individuals who learn most

rapidly under different instructional formats. Additional insight into visuospatial learning abilities and their role in knowledge acquisition would be obtained in studies designed to permit individuals to select their own type of instructions. Such studies would provide information about aptitude-treatment interactions and would also permit examination of the metacognitive aspect of the instructional process, i.e., individuals' knowledge of their own abilities and their judgments as to which instructional modes facilitate their own learning efforts.

Findings from the second study suggest that macrospatial cognitive abilities are not adequately assessed by available psychometric techniques. It is important to replicate and strengthen this tentative conclusion. As suggested earlier, furture efforts should concentrate on developing and implementing instruments for measuring macrospatial abilities and on establishing the external validity of these instruments.

Despite the fact that visuospatial tasks are a fundamental part of everyday life and an essential component in many jobs, relatively little research has been invested in examining the basic workings of the visuospatial information processing system. Progress toward rectifying this situation necessarily involves steps that include an operational taxonomy of spatial abilities, improved means of assessing spatial abilities, and analyses of real-world spatial tasks.

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